

19/07/18

UNIT - II

Performance of Transmission Lines:-

→ Basically the transmission lines are classified into Based on its operating voltage and length of lines They are:-

(i) Short transmission line:-

Distance of line < 80 km,

operating voltage < 20 kV.

(ii) Medium transmission line:-

length of line = 80 km to 160 km

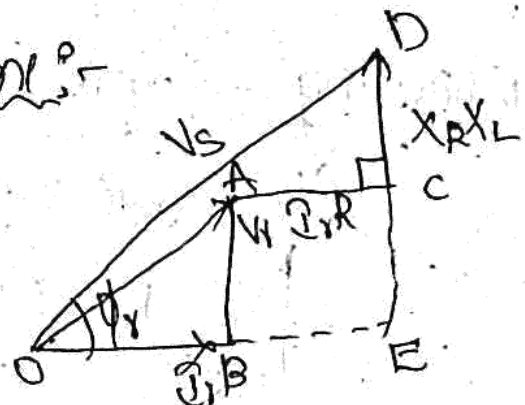
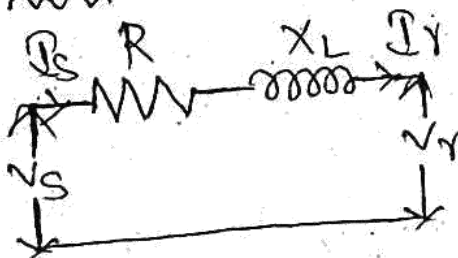
operating voltage < 100 kV.

(iii) Long transmission line:-

→ distance of line > 160 km.

operating voltage > 100 kV.

(i) Short transmission line:-



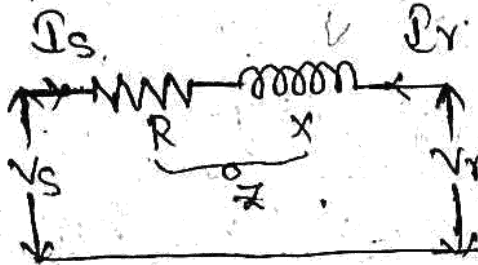
Here, $I_s = I_r = I$.

$$\therefore \text{Voltage Regulation} = \frac{V_s - V_r}{V_r} \times 100.$$

$$\% \text{ Efficiency} = \frac{V_r I_r \cos \phi_r}{V_s I_s \cos \phi_s} \times 100.$$

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* ABCD Parameters of short transmission line.



→ from the two port network.

$$\begin{aligned} V_s &= AV_r + B I_r \quad \rightarrow (1) \\ I_s &= CV_r + D I_r \end{aligned}$$

Here, $I_s = I_r$

$$V_s = V_r + I_s \cdot Z$$

$$V_s = V_r + I_r \cdot Z \quad \rightarrow (2)$$

$$I_s = 0 + I_r$$

Comparing Eqn (1) & (2)
ABCD constants,

$$\begin{aligned} A &= 1, & B &= Z \\ C &= 0, & D &= 1. \end{aligned}$$

(ii) Medium Transmission Lines :-

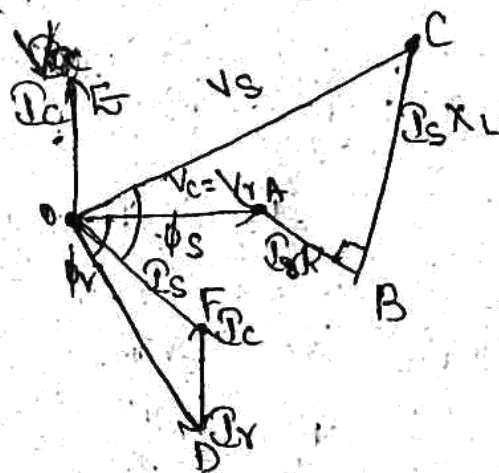
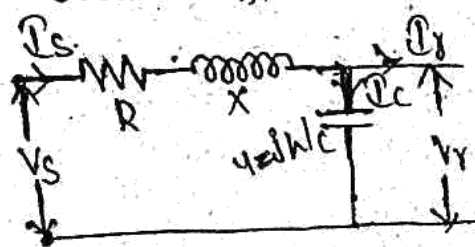
→ As the length of the line is 80 km to 160 km, the effect of the capacitance will be considered. Based on the placement of capacitor the analysis of medium transmission line can be taken as

(i) Capacitor End Method.

(ii) Nominal π -Method.

(iii) Nominal λ -Method.

(i) Capacitor End Method :-



→ From the phasor diagram horizontal line. " OA " is the receiving end voltage taken as reference vector.

→ " OD " is the receiving end current (I_r) which lags " V_r " by an angle ϕ_r .

→ " $OE = DF$ ", the current passing through capacitor which leads " V_r " by 90° .

→ "of" is equal to Sending End Current (I_s). Which is passing through the line and it is equal to vector sum of I_r & I_c .

→ AB = Resistive voltage drop parallel to "OD".

→ BC = Reactive voltage drop which leads by 90° .

→ OC = Sending End voltage

ABCD Parameters:-

→ from two port Network.

$$\left. \begin{aligned} V_s &= AV_r + BI_r \\ I_s &= CV_r + DI_r \end{aligned} \right\} \rightarrow (1)$$

from the single line diagram.

$$I_s = I_c + I_r$$

Here, $V_c = V_r$

$$I_c = \frac{V_c}{X_c}$$

$$I_c = \frac{V_r}{jX_c}$$

$$= V_r \cdot jY_c = V_r Y$$

$$\Rightarrow I_c = V_r Y$$

$$\Rightarrow \boxed{I_s = Y \cdot V_r + I_r} \rightarrow (2)$$

Here,

$$V_s = V_r + I_s \cdot Z \rightarrow (3)$$

Substitute Eqn (2) in (3) We get

$$V_s = V_r + |Y \cdot V_r + I_r| \cdot Z$$

$$V_s = V_r (1 + YZ) + I_r Z$$

$$V_s = (1 + YZ) V_r + I_r Z \rightarrow (4)$$

Comparing Eqn (1) & (2) & (4)

$$\begin{aligned} A &= 1 + YZ, & B &= Z \\ C &= Y, & D &= 1 \end{aligned}$$

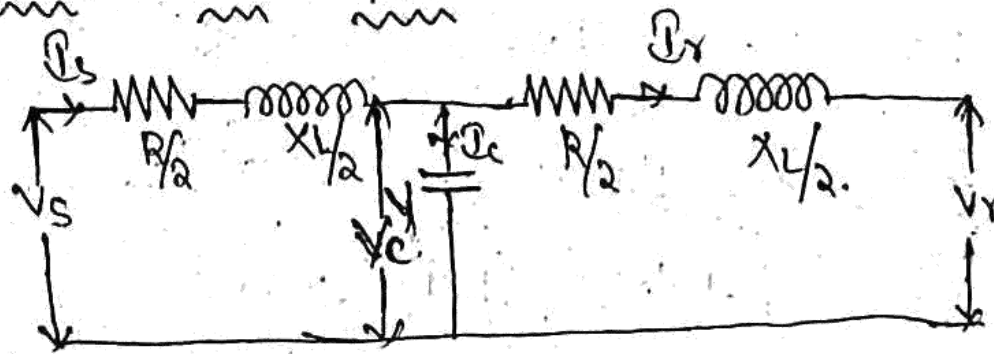
∴ The Voltage Regulation = $\frac{\text{No load receiving end voltage} - \text{full load receiving end voltage}}{\text{full load receiving end voltage}} \times 100$

$$\% V_R = \frac{V_r' - V_r}{V_r} \times 100$$

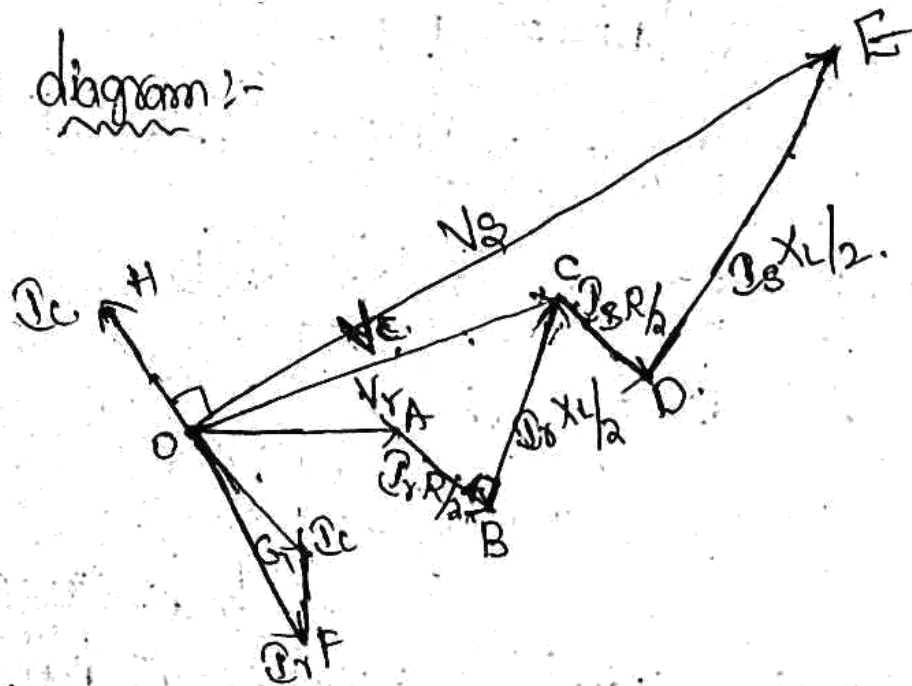
Where,

$$V_r' = \frac{V_s + j/wc}{(R + jX) - Ywc}$$

Nominal - π - N/w :-



Vector diagram :-



→ From the vector diagram,

- * OA is receiving End voltage, taken as Reference
- * AB is resistive voltage drop ($I_R R/2$) of the Right half of line
- * BC is Reactive voltage drop ($I_R jX_L/2$) of the Right half of the line.
- * OC is the voltage across Capacitor
- * CD is Resistive Voltage drop ($I_S R/2$) of the left half of the line.

* DE is the Reactive voltage drop ($I_s X_L/2$) at the left half of the line.

* " OE " is the Sending End voltage.

* OF is receiving End Current which lags " E_r ".

* " GF " is Current passing through the Capacitor.

* " OG " is Sending End Current.

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Problems:

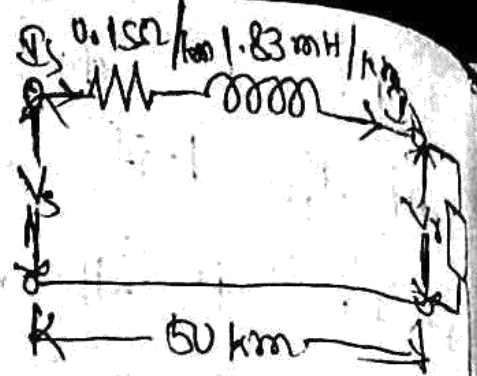
1. A 220 kV, 50 Hz, 3- ϕ transmission line has 50 kms long and it has resistance / phase is $0.15 \Omega/\text{km}$. The inductance per phase is $1.83 \text{ mH}/\text{km}$. The Shunt Capacitance is neglected, by using short transmission line model.

Determine the voltage and power at Sending End, voltage Regulation and Efficiency when the line is supplying 400 MVA, 220 kV at 0.8 p.f lagging.

Q01 :- Given data,

length $(L) = 50 \text{ km}$,

Resistance $(R) = 0.15 \Omega/\text{km}$



Sending End voltage = ?

Sending End power = ?

% voltage Regulation = ?

% Efficiency = ?

Receiving End power = 400 MVA

Receiving End voltage = 220 kV

→ from the single line diagram,

Sending End voltage $V_s = V_r + I_s \cdot Z$

Sending End power $P_s = \sqrt{3} V_s I_s \cos \phi_s$

Resistance for 50 km length $= 0.15 \times 50 = 7.5 \Omega$

Reactance for 50 km length $(X_L) = 2\pi f L \times 50$
 $= 28.74 \Omega$

Impedance $Z = R + jX_L = 7.5 + j28.74$

$$Z = 29.70 \angle 75.37^\circ \Omega$$

Here given that, $V_{r-L-L} = 220 \text{ kV}$

$$V_{r-ph} = \frac{220}{\sqrt{3}} = 127.01 \text{ kV}$$

Here $I_s = I_r$.

Receiving End power = 400 mVA.

Receiving End current = $\frac{400 \times 10^3}{\sqrt{3} \times 220 \times 10^3}$

$I_r = 1049.72 \text{ A}$

$\rightarrow I_r$ with $\text{pf lag} = 0.8$ $= 1049.72 \angle 36.86^\circ$

$I_r = I_s = 1049.72 \angle 36.86^\circ$

* Sending End voltage, $V_s = V_r + I_r Z$

$V_s = 127.01 \times 10^3 + (1049.72 \angle 36.86^\circ) (29.70 \angle 75.37^\circ)$

$V_s = 152645.11 \angle 7.30^\circ$

* Sending End power, $P_s = \sqrt{3} V_L I_L \cos \phi$
L-L sending voltage.

$V_{s(L-L)} = \sqrt{3} \times 152645.11 \angle 7.3$
 $= 264389.0 \angle 7.3$

$V_{s(L-L)} = 264.389 \angle 7.3 \text{ kV}$

$P_s = \sqrt{3} \times 264.389 \times 10^3 \times 1049.72 \cos(36.86 + 7.3)$

$P_s = 344.855 \text{ MW}$

$$\% \text{ voltage Regulation} = \frac{V_r' - V_r}{V_r}$$

$$V_r' = V_s = 264.389 \text{ kV.}$$

$$V_r = 220 \text{ kV.}$$

$$\% \text{ Regulation} = \frac{264.389 - 220}{220} \times 100$$

$$= 20.17 \%$$

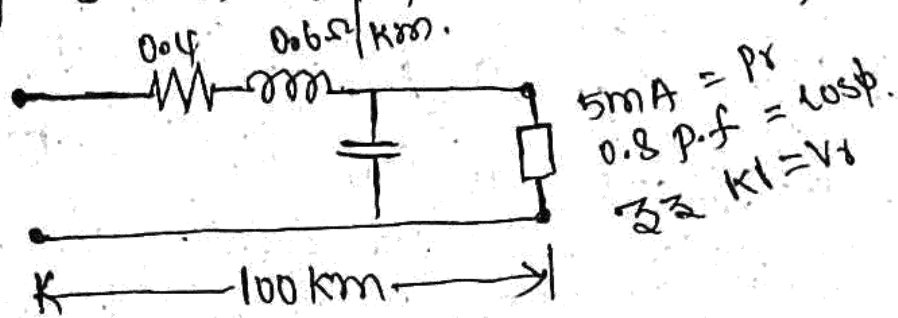
$$\% \text{ Efficiency} = \frac{\text{Receiving End power}}{\text{Sending End power}}$$

$$= \frac{400 \times 10^6 \times 0.8}{344.855 \times 10^6} \times 100$$

$$= 92.7 \%$$

2. A 3- ϕ Medium transmission line of 100-km long has $0.4 \Omega/\text{km}$ of Resistance and $0.6 \Omega/\text{km}$ of Reactance and the Admittance is $14 \mu\text{S}$, $V_r = 33 \text{ kV}$, Assuming the total Capacitance is localized at the Receiving End. then Determine (i) Sending End voltage and Current (ii) voltage Regulation (iii) % Efficiency

iv) Supplied Power factor When the line is delivering 5 mVA of power at 0.8 p.f. lagging



Sol:- Given data,

length = 100 km,

Resistance = $0.4 \Omega/\text{km}$.

Reactance = $0.6 \Omega/\text{km}$

Admittance (Y) = $1 \mu\text{M}\Omega$

Receiving End voltage (V_r) = 33 kV.

⇒ Sending End voltage (V_s) = $A V_r + B I_r$.
 Sending End Current (I_s) = $C V_s + D I_r$.

$$\therefore V_r (\text{L-L}) = 33 \text{ kV} = \frac{33}{\sqrt{3}} = 19.05 \text{ kV}$$

$$\Rightarrow I_r = \frac{\text{mVA} \times 10^6}{\sqrt{3} \times 33 \times 10^3} = 87.47 \text{ A.}$$

⇒ I_r lags with 0.8 p.f.

$$I_r = 87.47 \angle -36.86^\circ$$

∴ for Capacitance End method.

$$A = 1 + \gamma Z, \quad B = Z, \quad C = \gamma, \quad D = 1.$$

$$\Rightarrow \text{Resistance for 100 km length} = 0.4 \times 100 = 40 \Omega$$

$$\text{Reactance for 100 km length} = 0.6 \times 100 = 60 \Omega$$

$$\text{Admittance for 100 km length} = 14 \times 100 \times 10^{-6}$$

$$= 1.4 \times 10^{-3} \text{ S}$$

$$\therefore Z = R + jX_L = 40 + j60 = 72.11 \angle 56.3^\circ$$

$$\gamma = \frac{1}{Z_0} \frac{1}{x_c} = -j\omega C = 1.4 \times 10^{-3} \angle 90^\circ$$

$$\Rightarrow A = (1 + \gamma Z)$$

$$= (1 + (1.4 \times 10^{-3} \angle 90^\circ) (72.11 \angle 56.3^\circ))$$

$$= 0.9177 \angle 3.49^\circ$$

$$\Rightarrow B = Z$$

$$\Rightarrow C = \gamma, \quad D = 1.$$

$$\% \text{ Voltage Regulation} = \frac{V_r' - V_r}{V_r} \times 100$$

$$\Rightarrow V_s = (0.9177 \angle 3.49^\circ) (19.05 \angle 0^\circ) + (87.47 \angle -36.86^\circ)$$

$$V_s = (17.48 \angle 3.49^\circ) + (6307.46 \angle 19.44^\circ)$$

$$V_s = 17449.76 + j1064$$

$$+ (3050.88 + j2100)$$

$$V_s = 23645.22 \angle 4.1^\circ$$

$$= 23.645 \angle 4.1^\circ \Rightarrow V_L = 40.95 \angle 12.74^\circ$$

Sending End power = $P_r + \text{losses}$

$$\begin{aligned} \text{losses} &= 3 I_S^2 R = 3 \times (74.58)^2 \times 40 \\ &= 667461.168 \text{ W} \end{aligned}$$

$$\begin{aligned} \% \text{ Efficiency} &= \frac{5 \times 10^6 \times 0.8}{5 \times 10^6 \times 0.8 + 667461.16} \times 100 \\ &= 88.69 \% \end{aligned}$$

$$\therefore P_S = \sqrt{3} V_S I_S \cos \phi_S \Rightarrow$$

$$\frac{P_S}{\sqrt{3} \times V_S I_S} = \frac{5 \times 10^6 \times 0.8 + 667461.16}{\sqrt{3} \times 40.95 \times 10^3 \times 74.58}$$

$$\cos \phi_S = 0.88$$

$$\phi_S = 28.357$$

2. A 50 Hz, 3- ϕ transmission line is 250 km long. It has total series impedance of $40 + j100 \Omega$ and shunt admittance of $914 \times 10^{-6} \text{ S}$. It delivers 50 MW at 220 kV with 0.9 pf lagging. Calculate Sending End voltage, Sending End Current, % voltage Regulation, % Efficiency using Nominal π Method.

Sol :- Given data,

$$\text{length } (l) = 250 \text{ km.}$$

$$Z = (40 + j100) \Omega$$

$$\gamma = 914 \times 10^{-6} \text{ } \angle -$$

$$P_r = 500 \text{ MW}$$

$$V_r = 220 \text{ kV}$$

$$\cos \phi_r = 0.9 \text{ lag.}$$

$$\Rightarrow V_{r(l-l)} = 220 \text{ kV} = \frac{220}{\sqrt{3}} = 127.01 \text{ kV.}$$

$$\Rightarrow \text{Receiving End Current, } I_r = \frac{50 \times 10^6}{\sqrt{3} \times 220 \times 10^3}$$

$$I_r = 131.21 \text{ A.}$$

I_r with 0.9 p.f lag $\Rightarrow$

$$I_r = 131.21 \angle -25.84$$

$$\Rightarrow A = \left(1 + \frac{\gamma Z}{2}\right), \quad B = Z \left(1 + \frac{\gamma Z}{4}\right), \quad C = \gamma, \quad D = \left(1 + \frac{\gamma Z}{2}\right)$$

$$\therefore \gamma Z = (914 \times 10^{-6}) (40 + j100) \Omega$$

$$\gamma Z = (914 \times 10^{-6}) (107 \angle 68.19)$$

$$\boxed{\gamma Z = 0.098 \angle 68.19}$$

$$\Rightarrow \boxed{\frac{\gamma Z}{2} = 0.0492 \angle 68.19} \approx 0.018 + j0.045$$

$$\therefore A = \left(1 + \frac{\gamma Z}{2}\right) = (1 + 0.018 + j0.045)$$

$$\boxed{A = 1.018 + j0.045 \approx 1.01 \angle 2.53}$$

$$\therefore B = \frac{Z(1 + YZ/4)}{4}$$

$$\Rightarrow \frac{YZ}{4} = \frac{0.098 \angle 68.19}{4} = 0.0245 \angle 68.19$$

$$= 9.10 \times 10^{-3} + j0.0227$$

$$B = \frac{Z(1 + 9.10 \times 10^{-3} + j0.0227)}{4}$$

$$= \frac{Z(1.0091 + j0.0227)}{4} = \frac{107.7 \angle 68.19}{4} (1.00 \angle 1.28)$$

$$B = 107.7 \angle 69.47$$

$$\therefore C = 914 \times 10^{-6} \angle 0$$

$$\therefore D = \frac{1 + YZ/2}{2}$$

$$D = 1.01 \angle 2.53$$

$$\Rightarrow V_s = AV_r + B I_r$$

$$= ((1.01 \angle 2.53)(127.01 \times 10^3)) + (107.7 \angle 69.47)$$

$$= (130574.81 + j6167.19) + (10228.38 + j9750.58) \angle 131.21 \angle 2.53$$

$$V_s = 138383.45 + j15413.19$$

$$V_s = 139239.16 \angle 6.35 \Rightarrow 139.239 \angle 6.35$$

$$\Rightarrow 841.16 \angle 6.35$$

$$\Rightarrow I_s = CV_r + D I_r$$

$$= (914 \times 10^{-6} \angle 0)(127.01 \times 10^3) + (1.01 \angle 2.53)$$

$$(131.21 \angle 2.53)$$

$$I_s = 243.50 \angle 12.48$$

$$\% \text{ Voltage Regulation} = \frac{V_s' - V_r}{V_r} \times 100$$

$$V_r' = \frac{V_s \times (-j/\omega C)}{(R + jX_L) + (-j/\omega C)}$$

$$= \frac{V_s \times (1/4)}{(2 + 1/4)}$$

$$\% V.R = \frac{265.45 \frac{127.0}{127.0} - 220}{220} \times 100$$

$$= 20.65\% \quad 6.4\%$$

→ Sending End power = $P_s + \text{losses}$

$$\text{losses} = 3 I_s^2 R = 3 \times \left(\frac{207.87}{243.50} \right)^2 \times 40$$

$$= 71150.70 \text{ W} \quad 5.18 \text{ MW}$$

→ Sending End power

$$\% \text{ Efficiency} = \frac{50 \times 10^6 \times 0.9}{50 \times 10^6 \times 0.9 + 71150.70} \times 100$$

$$= 86.34\% \quad 90.61\%$$

$$P_s = \sqrt{3} V_s I_s \cos \phi_s$$

$$\cos \phi_s = \frac{P_s}{\sqrt{3} V_s I_s} = \frac{50 \times 10^6 \times 0.9 + 71150.70}{\sqrt{3} \times 24.16 \times 10^3 \times 243.50}$$

$$\cos \phi_s = 0.51 \Rightarrow \phi_s = 59.33^\circ$$

03/08/19

1. A 3- ϕ , 50 Hz transmission line, 100 km long delivers 25 MW and 110 kV at 0.8 p.f. lagging. The Resistance and Reactance of a km per phase ϕ /km are 0.3Ω & 0.5Ω respectively. Wbly a Capacitive admittance is $2.5 \times 10^{-6} \text{ S/km}$. Calculate

- (i) Sending End Voltage (ii) Efficiency using Nominal π and
(ii) Sending End Current Nominal T M/W.
(iii) Voltage Regulation

Sol:- ~~100~~ Given data,
length(l) = 100 km.

$$P_r = 25 \text{ MW.}$$

$$V_r = 110 \text{ kV.}$$

$$\cos \phi_r = 0.8 \text{ p.f.}$$

$$\text{Resistance (R)} = 0.3 \Omega$$

$$\text{Reactance (X)} = 0.5 \Omega.$$

$$(Y) = 2.5 \times 10^{-6}.$$

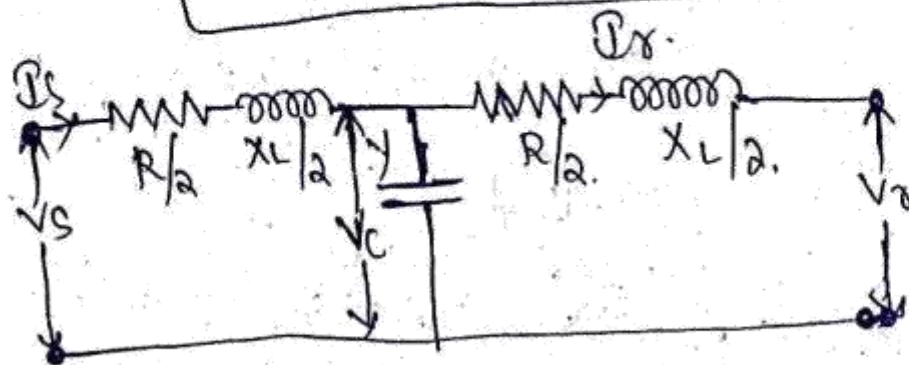
(i) Nominal π Network:-

~~110/2~~ $V_{r(l-L)} = \frac{110}{\sqrt{3}} = 63.50 \text{ kV.}$

$$\text{Receiving End Current } I_r = \frac{25 \times 10^6}{\sqrt{3} \times 110 \times 10^3}$$

P_r lags With 0.8 p.f

$$P_r = 131.21 \angle -36.86^\circ$$



ABCD parameters:-

$$A = \left(1 + \frac{YZ}{2}\right); \quad B = Z \left(1 + \frac{YZ}{4}\right); \quad C = Y; \quad D = \left(1 + \frac{YZ}{2}\right)$$

Resistance for 100 km length (R) = $0.3 \times 100 \Omega$
 $= 30 \Omega$

Reactance for 100 km length (X_L) = 0.5×100
 $= 50 \Omega$

Admittance for 100 km length (Y) = $2.5 \times 10^{-6} \times 100$
 $= 2.5 \times 10^{-4} \text{ S}$
 $= 0.25 \times 10^{-3}$

$$\Rightarrow Z = R + jX_L = 30 + j50 = 58.30 \angle 59.03^\circ$$

$$Y = 1/X_C = -j\omega C = 0.25 \times 10^{-3} \angle 90^\circ$$

$$\therefore A = \left(1 + \frac{YZ}{2}\right)$$

$$\frac{YZ}{2} = \frac{(0.25 \times 10^{-3} \angle 90^\circ)(58.30 \angle 59.03^\circ)}{2}$$

$$= 7.2875 \times 10^{-3} \angle 149.03^\circ = -6.24 \times 10^{-3} + j3.75 \times 10^{-3}$$

$$A = \left(1 + \frac{YZ}{2}\right) = \left(1 + (-6.24 \times 10^{-3} + j3.75 \times 10^{-3})\right) = 0.99 \angle 0.21^\circ$$

$$\therefore B = Z \left(1 + \frac{YZ}{4} \right)$$

$$YZ/4 = -3.12 \times 10^{-3} + 1.87 \times 10^{-3}j$$

$$\Rightarrow \left(1 + YZ/4 \right) = \left(1 + [-3.12 \times 10^{-3} + 1.87 \times 10^{-3}j] \right)$$

$$= 0.99 \angle 0.10$$

$$B = Z (0.99 \angle 0.10) = (58.30 \angle 59.03) (0.99 \angle 0.10)$$

$$B = 29.61 + 49.54j$$

$$\boxed{B = 57.71 \angle 59.13}$$

$$\therefore C = Y = 0.25 \times 10^{-3} \angle 90^\circ$$

$$\therefore \boxed{D = \left(1 + \frac{YZ}{4} \right) = 0.99 \angle 0.21}$$

(i) Sending End Voltage:-

$$V_S = AV_R + B I_R$$

$$V_S = (0.99 \angle 0.21) (63.50 \times 10^3) + (57.71 \angle 59.13) (13.21 \angle 13.21)$$

$$V_S = 69871.88 + j 3100.03$$

$$V_S = 69940.62 \angle 2.54 \Rightarrow 69.940 \angle 2.54$$

$$\boxed{V_S \Rightarrow 69.940 \times \sqrt{3} = 121.13}$$

(ii) Sending End Current:-

$$I_S = (V_R + D I_R)$$

$$I_s = (0.25 \times 10^{-3} \angle 90^\circ) (63.50 \times 10^3) + (0.99 \angle 0.21) (131.21 \angle -38.1^\circ)$$

$$I_s = 104.21 - j 61.66$$

$$I_s = 121.09 \angle -30.61^\circ$$

(iii) Voltage Regulation:-

$$\% \text{ Voltage Regulation} = \frac{V_s' - V_r}{V_r} \times 100$$

where,

$$V_s' = \frac{V_s \times (-j/\omega C)}{(R + jX_L) + (-j/\omega C)} = \frac{V_s \times (-j)}{Z + jY}$$

$$= \frac{121.13 \angle 2.54^\circ \times \left(\frac{1}{0.25 \times 10^{-3} \angle 90^\circ} \right)}{\left(\frac{58.30 \angle 59.03^\circ}{2} + \left(\frac{1}{0.25 \times 10^{-3} \angle 90^\circ} \right) \right)}$$

$$= 248.44 \angle -11.5^\circ$$

$$\% \text{ Voltage Regulation} = \frac{248.44 - 110}{110} \times 100$$

$$\% \text{ V.R} = 12.5\% \quad 11.5\%$$

(iv) Efficiency:-

$$\text{Sending End power} = P_s + \text{losses}$$

$$\text{losses} = 3 \times (I_s)^2 \times R = 3 \times (121.09 \angle -30.61^\circ)^2 \times 30$$

$$= 1.31 \text{ MW}$$

$$\therefore \text{Sending End power} = 25 \text{ MW} + 1.31 \text{ MW} \\ = 26.31 \text{ MW}$$

$$\% \text{ Efficiency} = \frac{25 \times 10^6 \times 0.8}{26.31 \times 10^6 \times 0.8} \times 100$$

$$\boxed{\% \eta = 95.02\%}$$

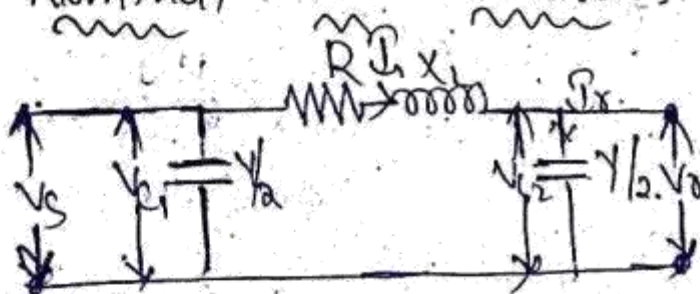
$$\text{Sending Power, } P_s = \sqrt{3} V_s I_s \cos \phi_s$$

$$\cos \phi_s = \frac{P_s}{\sqrt{3} V_s I_s}$$

$$\cos \phi_s = \frac{26.31 \times 10^6 \times 0.8}{\sqrt{3} \times 121.31 \times 10^3 \times 121.09} = 0.827$$

$$\boxed{\phi_s = 34.20^\circ}$$

② Nominal π - Network:-



$$V_{r(L-L)} = \frac{110}{\sqrt{3}} = 63.50 \text{ kV}$$

$$\boxed{I_r = 131.21 \text{ A}} \quad \text{lags with } 0.8 \text{ p.f.}$$

$$\boxed{I_r = 131.21 \angle -36.86^\circ}$$

ABCD Parameters:-

$$A = 1 + \frac{YZ}{2}, \quad B = Z, \quad C = Y \left(1 + \frac{YZ}{4} \right)$$

$$D = \left(1 + \frac{YZ}{4} \right)$$

Resistance for 100 km length = 30Ω .

Reactance for 100 km length = 50Ω .

Admittance for 100 km length = 0.25×10^{-3}

$$\Rightarrow Z = R + jX_L = 30 + j50 \Omega = 58.30 \angle 59.03^\circ$$

$$Y = \frac{1}{X_C} - jB_C = 0.25 \times 10^{-3} \angle 90^\circ$$

$$\therefore A = \left(1 + \frac{YZ}{2} \right) = 0.99 \angle 0.21^\circ$$

$$\therefore B = 58.30 \angle 59.03^\circ$$

$$\therefore C = Y \left(1 + \frac{YZ}{4} \right) = (0.25 \times 10^{-3} \angle 90^\circ) (0.99 \angle 0.10^\circ)$$

$$C = 2.475 \times 10^{-4} \angle 90.1^\circ$$

$$C = 0.00024 \angle 90.1^\circ$$

$$\therefore D = \left(1 + \frac{YZ}{4} \right) = 0.99 \angle 0.21^\circ$$

(i) Sending End Voltage:-

$$V_S = AV_R + B I_R$$

$$V_S = (0.99 \angle 0.21^\circ) (63.50 \times 10^3) + (58.30 \angle 59.03^\circ)$$

$$V_S = 63008.57 + j3117.01$$

$$= 63121 \angle 36.86^\circ$$

$$V_s = 70017.69 \angle 2.55 = 70.017 \angle 2.55$$

$$V_s = 70.017 \times \sqrt{3} = 121.27 \angle 2.55$$

(ii) Sending End Current:-

$$I_s = (V_r + D) I_r$$

$$I_s = (0.00024 \angle 90.1) (63.50 \times 10^3) + (0.99 \angle 0.21) (121.27 \angle 2.55)$$

$$I_s = 104.19 - j 62.29$$

$$I_s = 121.39 \angle -36.87$$

(iii) Voltage Regulation:-

$$\% V.R = \frac{V_r' - V_r}{V_r} \times 100$$

$$V_r' = \frac{V_s \left(\frac{V_r}{Z} \right)}{(R + jX_L) + \frac{V_r}{Z}} = \frac{118 \angle -12.9}{118 \angle -12.9}$$

$$\% V.R = 12.6 \Rightarrow \frac{118 - 110}{110} \times 100 = 7.27 \%$$

(iv) Efficiency:-

Sending End power = $P_r + \text{losses}$

$$\text{losses} = 3 \times (I_s)^2 \times 30$$

$$\text{losses} = 1.32 \text{ MW}$$

$$\Rightarrow \text{Sending End power} = 26.32 \text{ MW}$$

$$\Rightarrow \% \text{ Efficiency} = \frac{25 \times 10^6 \times 0.8}{26.32 \times 10^6 \times 0.8}$$

$$\boxed{\% \eta = 94.98 \%}$$

$$P_s = \sqrt{3} V_s I_s \cos \phi_s = \cos \phi_s = \frac{P_s}{\sqrt{3} V_s I_s}$$

$$\cos \phi_s = 0.82$$

$$\boxed{\phi_s = 34.91}$$

$$= \frac{V_s \times \frac{1}{2} \times \frac{1}{4}}{V_s \times \frac{1}{2} \times \frac{1}{2}}$$